

Ammonia oxidation an important source of nitrous oxide emissions in California cropping systems

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Overview

- Introduction: N_2O and soils
- N_2O pathways
- Objective
- C_2H_2 inhibition—Method I
- The dual isotope---Method II
- Conclusions

Ammonia oxidation pathways and nitrifier denitrification are significant sources of N_2O and NO under low oxygen availability

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The continuous increase of nitrous oxide (N_2O) abundance in the atmosphere is a global concern. Multiple pathways of N_2O production occur in soil, but their significance and dependence on oxygen (O_2) availability and nitrogen (N) fertilizer source are poorly understood. We examined N_2O and nitric oxide (NO) production under 21%, 3%, 1%, 0.5%, and 0% (vol/vol) O_2 concentrations following urea or ammonium sulfate $[(\text{NH}_4)_2\text{SO}_4]$ additions in loam, clay loam, and sandy loam soils that also contained ample nitrate. The contribution of the ammonia (NH_3) oxidation pathways (nitrifier nitrification, nitrifier denitrification, and nitrification-coupled denitrification) and heterotrophic denitrification (HD) to N_2O production was determined in 36-h incubations in microcosms by ^{15}N - ^{18}O isotope and NH_3 oxidation inhibition (by 0.01% acetylene) methods. Nitrous oxide and NO production via NH_3 oxidation pathways increased as O_2 concentrations decreased from 21% to 0.5%. At low (0.5% and 3%) O_2 concentrations, nitrifier denitrification contributed between 34% and 66%, and HD between 34% and 50% of total N_2O production. Heterotrophic denitrification was responsible for all N_2O production at 0% O_2 . Nitrifier denitrification was the main source of N_2O production from ammonical fertilizer under low O_2 concentrations with urea producing more N_2O than $(\text{NH}_4)_2\text{SO}_4$ additions. These findings challenge established thought attributing N_2O emissions from soils with high water content to HD due to presumably low O_2 availability. Our results imply that management practices that increase soil aeration, e.g., reducing compaction and enhancing soil structure, together with careful selection of fertilizer sources and/or nitrification inhibitors, could decrease N_2O production in agricultural soils.

Previous research on N_2O and NO emissions from soil has identified N application rates, fertilizer types, soil moisture, and soil texture as main factors affecting N_2O and NO emissions (9, 10). Although the importance of O_2 as a controlling factor in regulating the magnitude and pathway of N_2O and NO production has been recognized (6, 11, 12), O_2 concentrations are rarely measured, and soil moisture content has generally been accepted as a measurable proxy of O_2 availability (13). For example, optimum conditions for N_2O emissions via denitrification have been assumed to exist at water-filled pore space (WFPS) of 70–90% (9, 14), whereas N_2O emissions at lower WFPS have often been attributed to nitrification (14–16). However, soil moisture controls not only the diffusion of O_2 , but also substrate availability (17) and microbial activity. In previous studies, it has therefore been difficult to distinguish between the effects of O_2 and substrate availability on N_2O production. For these reasons, the role of O_2 in regulating N_2O and NO production in soil has been challenging to explain (18–20).

In pure culture studies, the reduction of NO_2^- to NO and N_2O by autotrophic NH_3 oxidizers (21) occurred at increasing rates as O_2 concentration declined (22, 23). Thus, under limiting O_2 concentrations ND could contribute significantly to N_2O production in soil (20, 24). However, differentiating between ND and other N_2O -producing processes has been methodologically challenging. Acetylene (C_2H_2) at concentrations of 0.1–10 Pa (0.01% by volume) inhibits NH_3 oxidation by autotrophs, such as *Nitrosomonas europaea* (25, 26), and therefore ND, NN, and NCD; at these concentrations, C_2H_2 does not inhibit NH_3 oxidation by heterotrophs (26), which might be the source of N_2O

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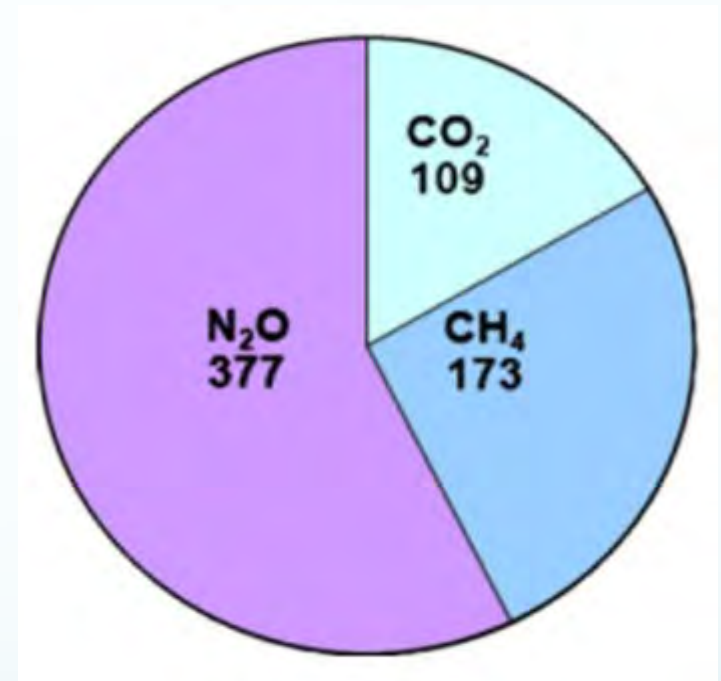
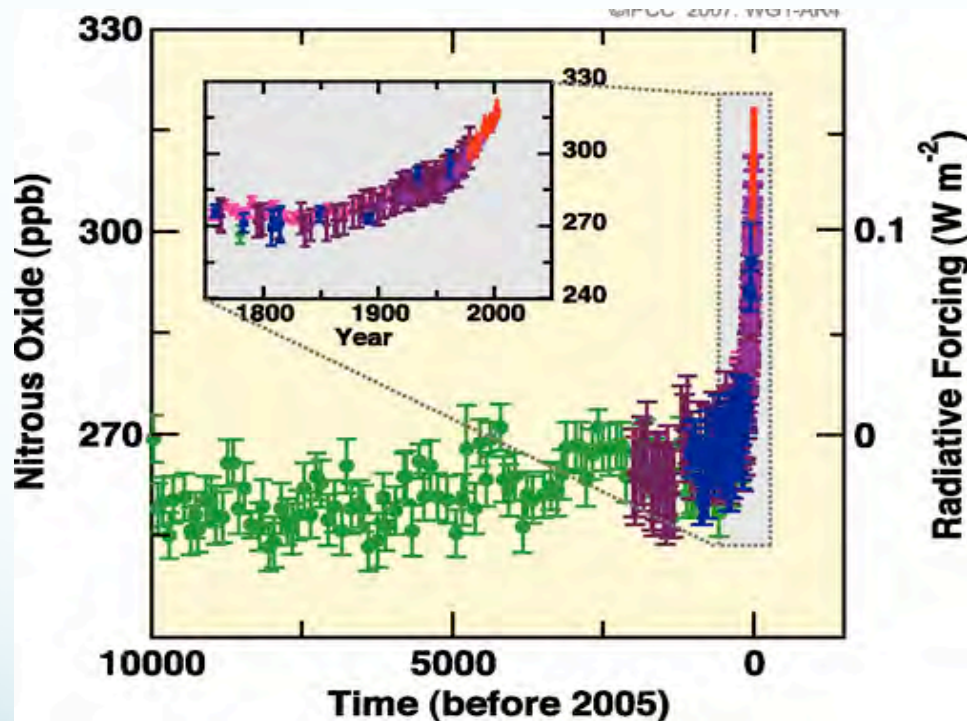
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N₂O concentration in atmosphere

N₂O emission from U.S. Agriculture, 2005



Unit: million tonnes CO₂ eq.





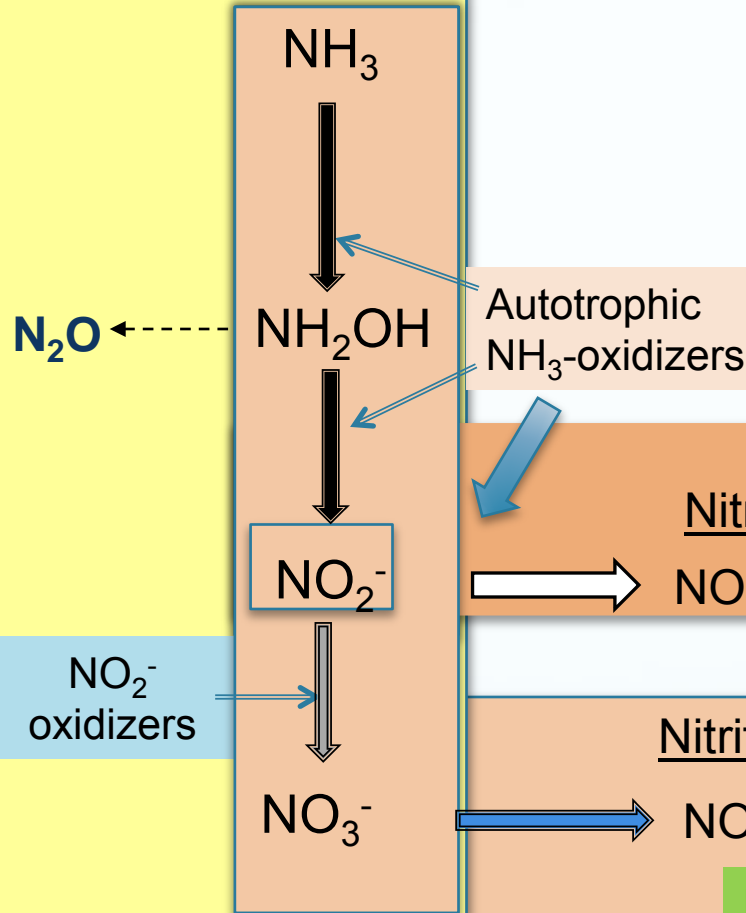
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N_2O pathways

Nitrification



- Nitrifier nitrification---NN
- Nitrifier denitrification--ND
- Nitrification-coupled denitrification--NCD
- Denitrifier denitrification--DD

Nitrifier Denitrification



Nitrification- coupled Denitrification



Heterotrophic denitrifiers

Denitrification



Objective

To investigate the influence of O_2 availability and fertilizer type on N_2O production pathways in agricultural soil

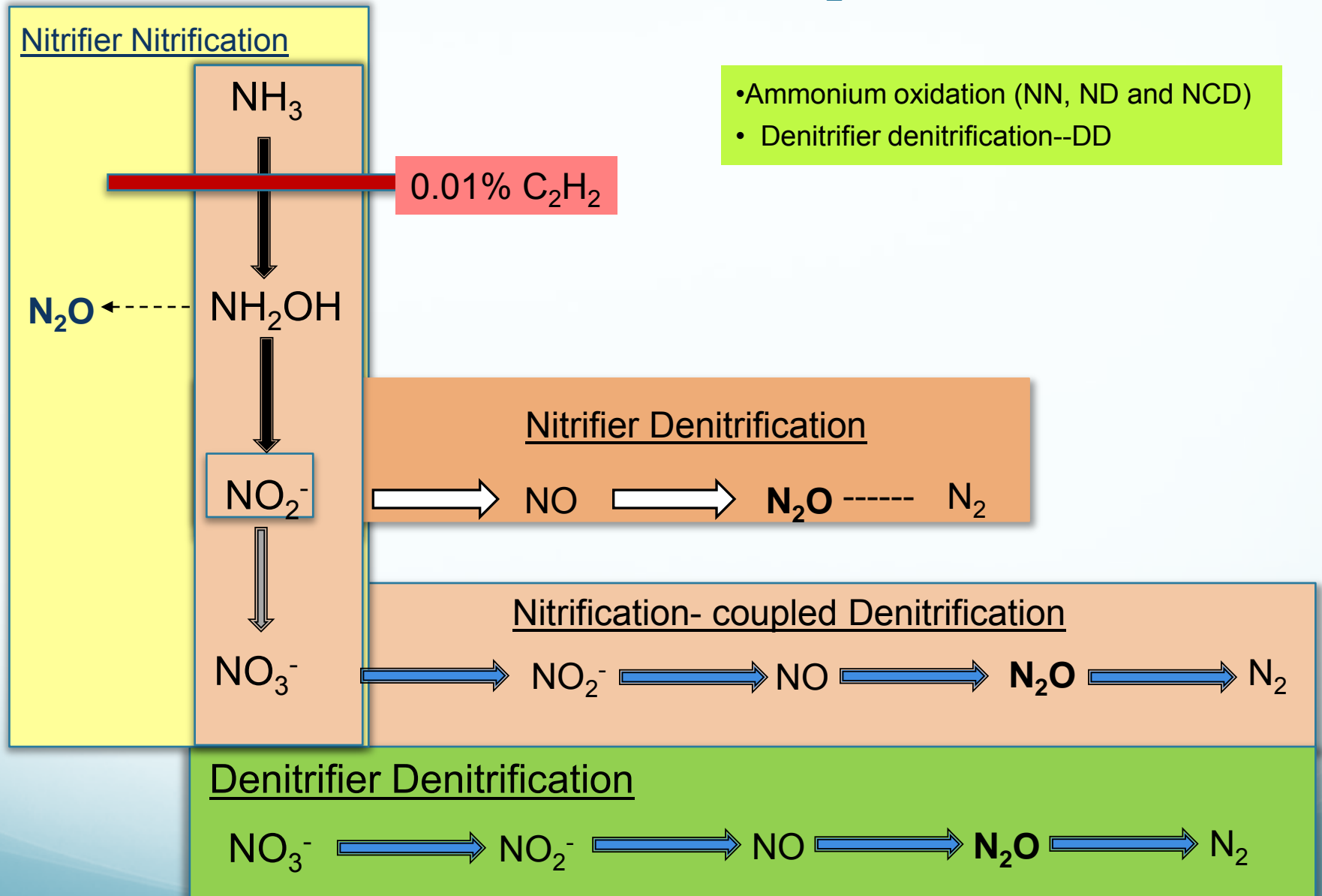


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N₂O pathways

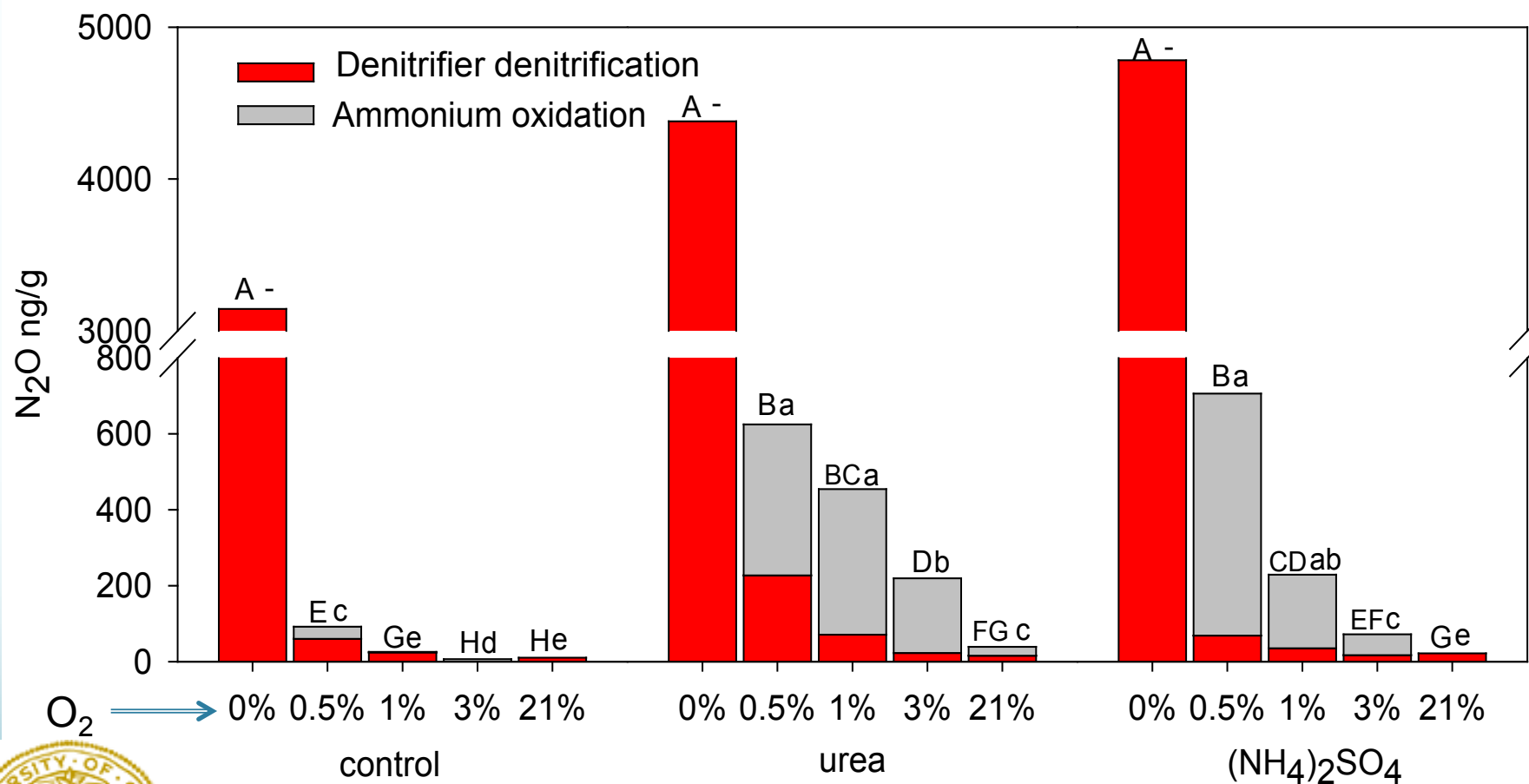


C_2H_2 inhibition—Method I

- Experiment design
 - ✓ Soil: clay loam (soil pre-incubation for 7 days), pH 5.6, TN 0.14%, TC 1.6%
 - ✓ randomized complete block design
 - ✓ Fertilizer: none, urea, $(NH_4)_2SO_4$ (50 mg N kg^{-1} soil)
 - ✓ O_2 level: 0%, 0.5%, 1%, 3%, 21% (concentration in microcosm headspace)
 - ✓ C_2H_2 : with C_2H_2 , without C_2H_2
 - ✓ Incubation period: 36 hours
 - ✓ 50% water holding capacity, 22°C



Result--- C_2H_2 inhibition method



Result ----C₂H₂ inhibition method

At O₂ > 0%, ammonium oxidation is the
dominant pathway of N₂O



Which pathway in ammonium oxidation is responsible for these changes ?



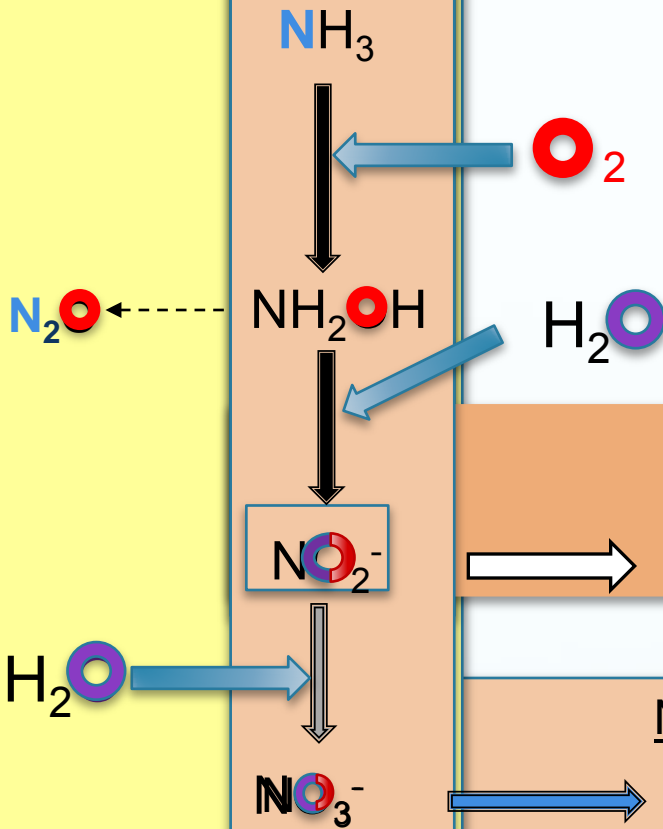
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The ^{15}N and ^{18}O isotope---Method II

Nitrifier Nitrification



- NN— no O come from H_2O
 - ND--- $\frac{1}{2}$ O come from H_2O
 - NCD--- $\frac{2}{3}$ O come from H_2O
 - DD --- no O come from H_2O
- $\left. \begin{array}{l} \text{• NN— no O come from } \text{H}_2\text{O} \\ \text{• ND--- } \frac{1}{2} \text{ O come from } \text{H}_2\text{O} \end{array} \right\} ^{15}\text{N from } \text{NH}_4^+$
 $\left. \begin{array}{l} \text{• NCD--- } \frac{2}{3} \text{ O come from } \text{H}_2\text{O} \\ \text{• DD --- no O come from } \text{H}_2\text{O} \end{array} \right\} ^{15}\text{N from } \text{NO}_3^-$

Nitrifier Denitrification



Nitrification- coupled Denitrification

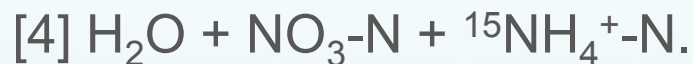


Denitrifier Denitrification

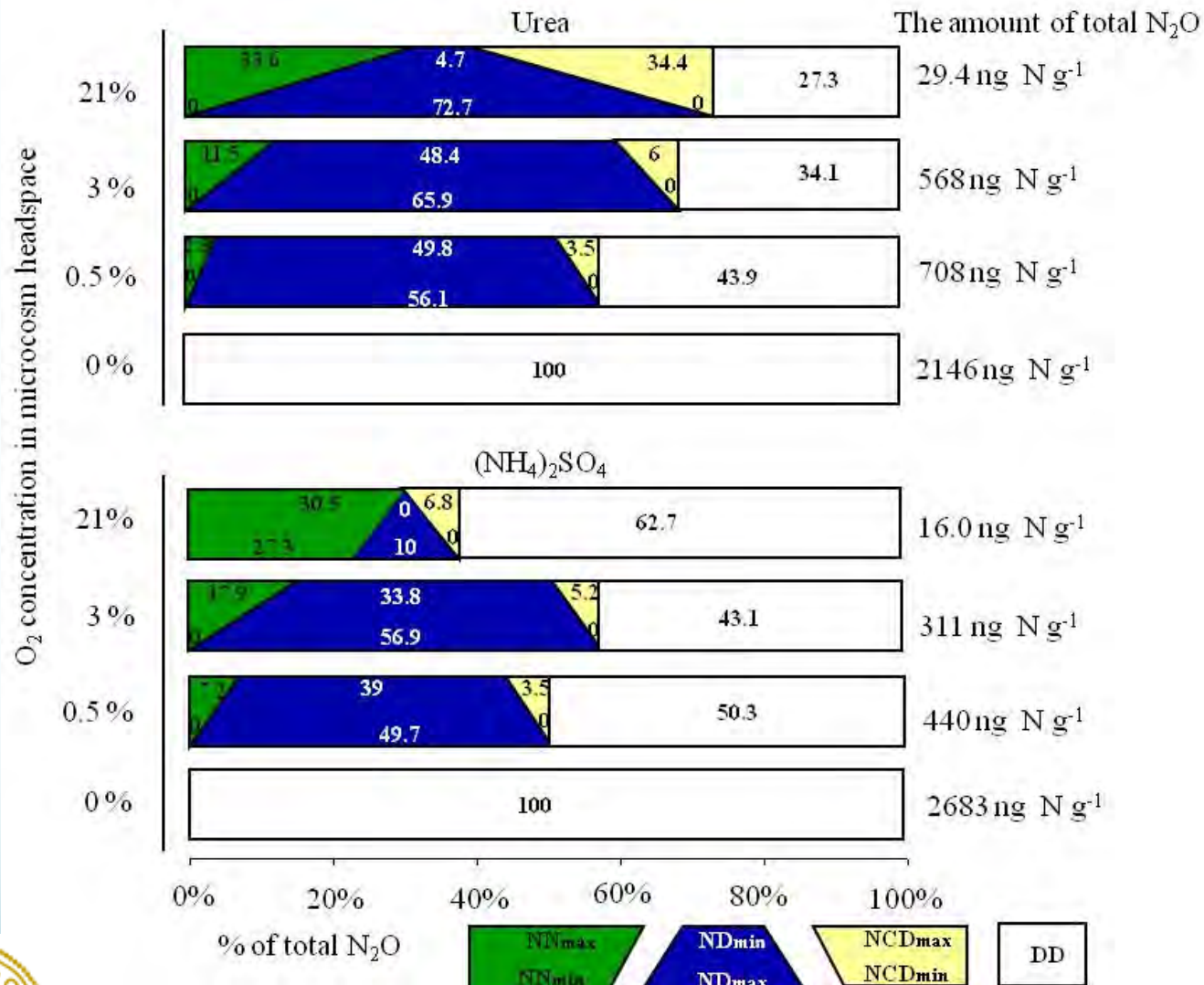


The dual isotope---Method II

- ^{15}N and ^{18}O experiment -----same condition as method I
- ❖ Each treatment have 4 sub treatment:



N₂O pathways—Method II

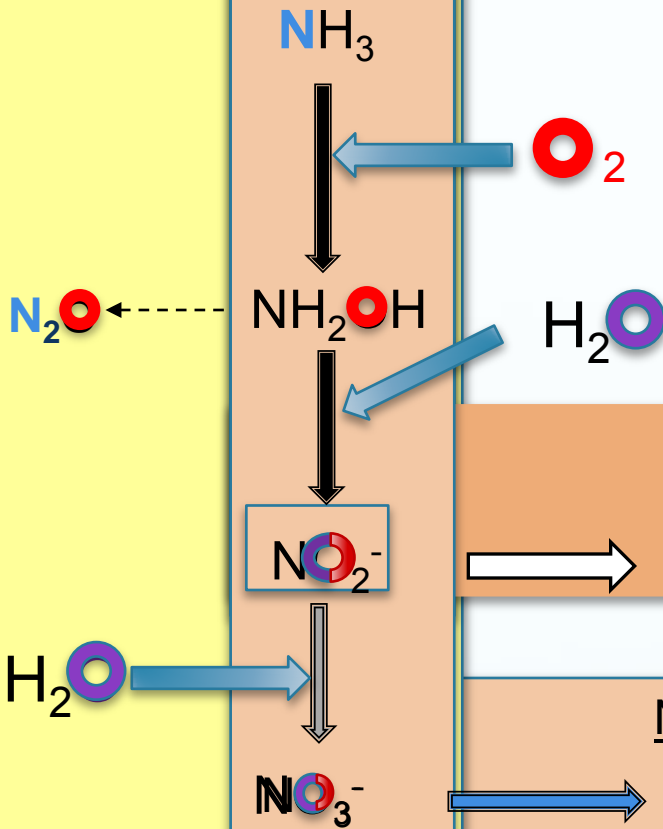


Nitrifier nitrification---
IN; Nitrifier
enitrification—ND;
litrification-coupled
enitrification—NCD;
Denitrifier
enitrification--DD



The ^{15}N and ^{18}O isotope---Method II

Nitrifier Nitrification



- NN— no O come from H_2O
- ND--- $\frac{1}{2}$ O come from H_2O
- NCD--- $\frac{2}{3}$ O come from H_2O
- DD --- no O come from H_2O

} ^{15}N from NH_4^+
 ^{15}N from NO_3^-

Nitrifier Denitrification



Nitrification- coupled Denitrification



Denitrifier Denitrification



Conclusions

- N_2O from ammonium oxidation **increased** as O_2 concentration **decreased**-----was **main source** of N_2O when O_2 concentration was $\geq \underline{0.5\%}$
- **MORE** N_2O derived from nitrifier denitrification in urea than in $(\text{NH}_4)_2\text{SO}_4$ soil
- **Management implications:** Type of fertilizer; soil management, fertilizer application; nitrification inhibitors



Questions?



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